

EVIDENCE OF ATMOSPHERIC TRANSPORT
AND DEPOSITION OF TOXIC SUBSTANCES
IN CANADIAN ARCTIC SNOW:
1986 PROGRESS REPORT

(Limited Distribution)

Prepared by
D.J. Gregor
Water Quality Branch
Western and Northern Region
Environment Canada

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DISCLAIMER

The work discussed in this report has been funded by a number of government agencies; however, at this time the opinions and conclusions expressed herein remain those of the author and do not necessarily coincide with those of the government agencies or their staff who have supported this project.

Citation of this report should not be without the prior written consent of the author and/or Mr. Wm. Gummer, Chief, Water Quality Branch, Western and Northern Region, Environment Canada. The mailing address for both is:

Water Quality Branch
Environment Canada
1901 Victoria Avenue
Regina, Saskatchewan,
Canada, S4P 3R4

telephone (306) 780-5322

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SUMMARY AND PRELIMINARY OBSERVATIONS

The 1986 snow sampling program for the NWT was undertaken, to a large extent, as a pilot study to determine whether or not it was possible to detect the presence of anthropogenic contaminants in the Arctic snow. If this was possible, it would confirm that quantities of these substances, which have been known to be present in the Arctic atmosphere during the winter months, are being deposited through wet and dry deposition onto the snowpack of the Arctic and consequently are entering the Arctic aquatic environment via this pathway. Since the presence of contaminants have been identified in Arctic marine mammals and fish, it is essential to identify the pathways for the contaminants if management of the contaminants is to be feasible. Also, if anthropogenic contaminants are entering the snowpack, these will include undoubtedly acid precursors which could impact upon areas of the Arctic aquatic environment which are highly sensitive to acidification due to low buffering capacities.

During the spring of 1986, snow pack samples representing snow accumulation for the winter of 1985/86 were collected at a total of 13 sites widely distributed throughout the Keewatin and High Arctic Districts of the NWT. One of these sites was collected in triplicate and snow samples representative of the preceding 4 winters were also collected from the site located on the Agassiz Ice Cap. All samples were collected as large volume snow samples in Teflon bags, melted at room temperature

and extracted in the field laboratories for analyses of organic contaminants. Subsamples were also prepared for analyses of major ions, some physical parameters, and selected metals and trace elements.

Although analyses of the samples is continuing, considerable information is available. By way of summary, several items are worth noting. First, proximity to the ocean is a definite factor in the major ion chemistry of the snow and this effect needs to be normalized if spatial comparison of the samples is to be feasible. There is evidence that the snowpack of the Keewatin District tends to be acidic and that this occurs in a region in which the surface waters are highly sensitive to acidification. In addition, the incorporation of terrestrial material within the snow pack has an effect on the inorganic chemistry of the snow although the samples from the Agassiz Ice Cap are believed to approximate the wet and dry deposition of inorganic contaminants. Metals and trace elements commonly detected in the snow samples were Al, Ba, Cr, Cu, Fe, Mn, Pb, Sr and Zn.

Polycyclic aromatic hydrocarbons (PAHs), derived from the combustion of coal tars, have been reported to be transported to the Arctic via long range atmospheric transport. A number of PAHs have been detected in the snow samples at very low concentrations; however, the possibility of contamination of these samples during collection, transportation, storage and melting can not be eliminated. Therefore, the concentration of PAHs in Arctic snow requires further investigation of the suspected contamination problem.

Based upon the detection of Toxaphene in a number of the snow samples, particularly from the High Arctic, there is evidence that anthropogenic contaminants are being deposited onto the snow pack in measurable quantities following atmospheric transport from the mid latitudes. There is no known explanation for the presence of Toxaphene in the Arctic snow other than via this pathway. Sample contamination seems highly unlikely. Also, it is noteworthy that all but one of the Agassiz Ice Cap samples contained quantifiable concentrations of Toxaphene and due to the nature of these samples it seems highly unlikely that accidental contamination could have occurred. Although the Canadian useage of Toxaphene has been very limited, and the once heavy useage in the southern U.S. is considerably reduced due to more restrictive regulation, the past and current useage in Europe and Asia is unknown and warrants further assessment due to the suspected importance of these source areas to the Arctic. Further historical sampling of Arctic glaciers should indicate a temporal trend in this compound.

The investigation of organochlorine residues (OCs) and total polychlorinated biphenyls (PCB) is continuing. Based upon the results to date, there seems to be limited contamination of these samples with widespread detection at quantifiable levels of α -BHC, Lindane, Heptachlor Epoxide, γ -Chlordane, α -Chlordane, α -Endosulfan and Dieldrin. Included with the samples for which these compounds were detected are the Agassiz Ice Cap samples. The total PCB concentrations, however, indicate problems with contamination to an unknown extent. A

certain portion of the measured PCB is likely indicative of the atmospheric loading to the Arctic snow; but, this can not be separated from sample contamination with the present data.

Based upon the information available to date, it is essential to continue the survey of the Arctic snow chemistry for at least one more season. This years experience has demonstrated that the techniques developed for this work have been successful, particularly with respect to the in-field extraction of large volume samples. Continuing laboratory analyses will help to define an analytical protocol for these snow samples which should provide more definitive information regarding the important toxicants resident in the Arctic snow. In addition, the work proposed for the forthcoming field season will help to address some of the contamination problems which have arisen. The field program for 1987/88 is planned as an expansion of this survey and will include continuation of the spatial aspects of the work and emphasis on the last 25 to 40 years of temporal record contained in the glacial snows of the High Arctic. The successful completion of this work is dependent upon the continued support of Environment Canada, in particular the logistical and field support of Water Quality Branch, Western and Northern Region; and, Inland Waters Directorate, Yellowknife; as well as the logistical and/or financial support provided by the Polar Continental Shelf Project; Energy, Mines and Resources; Indian and Northern Affairs and the Government of the Northwest Territories.

INTRODUCTION AND BACKGROUND

The Northwest Territories (NWT) represent 34% or 3.38 million square kilometres of Canada's land mass. A large portion of this area is mainland (Western and Keewatin Arctic) while the remainder is comprised of islands within the high Arctic. Most development and concomitant knowledge, including the quality of the aquatic environment, has been directed toward the Western Arctic and, specifically, the Mackenzie Valley.

The remainder of the NWT has all but been ignored with respect to assessing the aquatic quality, probably as a result of (i) the belief that a lack of extensive development means that the environment remains naturally pristine; and (ii) the remoteness increases costs and complicates logistics of even routine measurement and assessment activities. However, as the magnitude of the effect of acid rain and the long range transport of atmospheric pollutants has been recognized on a global scale, so the sense of environmental security afforded by remoteness from human activities has proven to be tenuous if not non-existent.

There is a growing pool of evidence which indicates levels of contamination of certain components of the marine and freshwater biota of the NWT are indeed showing measurable levels of contamination by substances which are known to be anthropogenic in origin. The results of contaminant residue

analyses for metals and organochlorine compounds have been reported for Arctic marine mammals and fish by Muir et al (1985) and Norstrom et al (1985). The ultimate significance of the presence of contaminants in these biota; however, is the potential impact upon the human population of the region, especially those who depend on "country foods", including fish and seals, as a major contribution of their diet. Wong (1985) has completed an excellent review of the dependence of many of the Arctic communities upon country foods and outlines some of the important characteristics regarding preparation and simplicity of diet as well as summarizing the available information on chemical residues in fish and wildlife species in the Canadian north. Based upon this information, the Canadian Department of Health and Welfare (NH&W) in conjunction with Indian and Northern Affairs Canada (INAC) have undertaken a study on the contaminant burden in affected human populations, specifically the community of Broughton Island. As well, this study is designed to provide a better understanding of the dietary habits of the community residents (Kinloch and Kuhnlein, 1986).

The pathway for these contaminants to the Arctic biota is not clearly defined at this time. Norstrom et al (1985) postulated that the major source was background oceanic contamination; however, the importance of atmospheric contamination and subsequent deposition and incorporation within the aquatic system can not be ruled out. After primary emission to the atmosphere from, for example, smoke stacks as combustion by-products and agricultural spraying of herbicides, many volatile organic air pollutants are dispersed over the surface

of the earth by repeated deposition and volatilization. If the element or compound is chemically stable, particularly with respect to solar radiation, this transport must result in the general migration of such substances to the colder regions of the earth (Dehne and Ottar, 1984). Relevant compounds are heavy metals and trace elements, many of the more persistent aromatic and polycyclic aromatic hydrocarbons and most of the polychlorinated hydrocarbons. Water soluble substances are effectively deposited by precipitation while hydrophobic compounds are deposited as dry fallout or through adsorption onto particles.

This movement of anthropogenically contaminated aerosols (an aerosol is a collection of solid particles and/or liquid, suspended in the atmosphere) in the Arctic has been argued to be derived, at least in part, from the adiabatic motion of air parcels (Carlson, 1981). Carlson has observed that northward moving airstreams south of the polar front jet tend to be rather warm and moist, ascend very quickly to the upper troposphere, saturate rapidly and remain in the vicinity of the polar front jet. In mid-winter the polar front jet is located around 40 to 45 degrees North over the continental land masses of Asia and North America. The meridional transport of cold dry polluted air from north of the polar front is the source, Carlson speculates, for the layers of aerosols observed in the Arctic. This transport occurs relatively quickly, such that the air mass arrives in the Arctic in perhaps less than 10 days, and since the air mass is dry initially, it never becomes saturated and reaches the Arctic at the relatively low altitudes (1 to 3 km) at which the highest concentrations of

aerosols are found, and with no significant loss of its load of contaminants through precipitation. Areas such as south central Ontario and Eurasia have large industrial complexes northward of the polar front throughout much of the winter period. As spring approaches and the front gradually moves north again, the frequency of intrusion into the Arctic by these polluted, cold, dry air masses decreases and eventually cease for the summer (Carlson, 1981).

Excess sulphate in the Arctic atmosphere has been observed to be at a minimum during the period June through September. Barrie et al (1981) have observed that the concentration of light scattering aerosols, as observed at Mould Bay and Igloolik, NWT, varies persistently from year to year through a minimum from June to September to a 20-40 fold higher maximum from January to April. Meteorological analyses of these data led to the suggestion that the polar atmosphere can be viewed as a large reservoir that periodically exchanges air with the southern air masses. Its particulate burden depends on the pollutant scavenging efficiency of the atmosphere, which is generally high in summer and low in winter; thus, accounting for the annual cycle. The concentrations of the aerosols appear to be uniform throughout the Arctic based on comparable data from Barrow, Alaska (Rahn and McCaffrey, 1980). Based upon trajectories and analysis of synoptic weather patterns, Barrie et al (1981) concluded that pollution sources in Siberia, Europe and eastern North America all contribute to the Arctic aerosols. Which source is dominant depends very much upon the prevailing weather patterns. On the bases of climatological averages, it is proposed that the influence of

Siberian sources of pollution are strongest throughout the fall and winter when the Siberian high is strongest. Eastern North American and European emissions are more likely to reach the Arctic in late winter and early spring. Transport of North American pollution northward depends on the presence of cold highs which tend to develop in late winter. Many of the routes to the Arctic from Europe tend to be over open water which promotes scavenging of pollutants, at least until freeze up, minimizing the importance of European sources until late winter. The relative importance of source areas is supported by the work of Ratz (1984) and Lowenthal and Rahn (1984). The latter authors also note that the sheer size of the USSR is an important factor in addition to the strong transport pathways emanating from its interior.

Recent work on using natural pollen as a tracer to demonstrate atmospheric contamination and deposition to the snow pack in the Arctic has proven to be very interesting. Barrie et al (1981) observed pollen collected from large volume air samples at Mould Bay. They noted that fully 80% of the pollen is non-Arctic in origin; however, they go on to say that the large size of most pollen species precludes their use as direct air mass tracers due to their propensity for deposition and reentrainment. Bourgeois et al (1985) summarized the work to date on the use of pollen in Arctic snow as a tracer including the results from their study of 15 large volume snow samples from widely dispersed sites. Two particularly relevant conclusions of this study are: first, there is a steep exponential decay of pollen deposition rates north of the tree line and an absence of deposition rates within the area of the

Arctic Islands suggesting that pollen transport to the Arctic is not simply a meridional transport phenomenon; and, second, the flatness of the distribution suggests long trajectories and complete mixing from various source areas with the possibility of Eurasian sources. Further refinement of the pollen record in the Arctic is continuing (personal communication, J. Bourgeois).

The extent of contamination of the Arctic atmosphere by the massive transport of polluted air from mid-latitude sources is at such a scale and intensity that it has become known as the phenomenon called Arctic haze. The first description of Arctic haze was in an article on visibility in the polar regions by Dr. J. M. Mitchell Jr., in 1957. Mitchell observed that the haze, which he defined as diffuse bands of tropospheric aerosol, occurred northward of about 70 degrees and at altitudes of up to 9000 metres. Vertical visibility was unaffected by Arctic haze while horizontal and slant visibility could be reduced to as little as 3 to 8 km. Arctic haze was essentially forgotten until 1972 when numerous flights to study the ice pack experienced haze layers which appeared brownish-yellow in colour, similar to the familiar urban haze layers (Rahn and Shaw, 1982).

Initial work on the chemistry of the Arctic aerosol is summarized by Rahn and Shaw (1982). At that time, emphasis had been on the trace element chemistry in an effort to identify source areas using elemental signatures. Heidam (1984) summarizes and interprets the chemical composition of the Arctic aerosol at a number of sites in Greenland, again

with emphasis on trace elements.

The history of Canadian observations of the chemistry of the Arctic atmosphere has been summarized by Whelpdale and Barrie (1982) and by Barrie and Hoff (1985). The Canadian Arctic Air Sampling Network (CAASN) was initiated at Mould Bay, NWT, in April, 1979. In November, 1979, a second station was added at Igloolik and a third was commissioned at Alert in July 1980. These stations collected particles on a weekly averaged basis by means of filtering large volume air samples (16000 m^3) near the surface. These samples were analyzed for 25 chemical compounds and trace elements (Table 1). In May, 1984, the network was reduced to one station at Alert.

Precipitation chemistry is analysed in samples collected at Canadian Network for Sampling Precipitation (CANSAP) stations. Northern sites included Inuvik, Fort Reliance, Mould Bay and Hay River in NWT and Whitehorse in the Yukon. Data on soluble ions in wet-only buckets is usually reported on a monthly averaged basis. Due to very low quantities of precipitation, results from the high Arctic stations, Inuvik and Mould Bay, have been available only as annual averages for 1980 and 1981 for Inuvik. In those years, the average pH of precipitation at Inuvik was 6.8 and the average concentration of seasalt-corrected sulphate was 9 and 15 micromoles/L.

In June 1984, the decommissioned Mould Bay large volume air sampler was modified to collect samples of aerosol for analyses of chlordanes and its oxidation/metabolic products using both glass fibre filters and polyurethane foam plugs. No chlordanes

($<0.1 \text{ pg/m}^3$) was detected on the filters indicating that there was little if any chlordane associated with the particulate matter. There was no detectable amounts of any of the chlordane isomers on either the filter or foam blanks; however, the foam plugs showed measurable amounts of gas phase chlordane (Table 2).

Dehme and Ottar (1984) measured the presence of polychlorinated hydrocarbons in the atmosphere of the Arctic using large volume air samplers with an aerosol filter and two plugs of polyurethane foam. The samples, collected between 1980 and 1983, indicated that more than 99% of the polychlorinated hydrocarbons were in the gas phase. The results for two sampling periods in early fall and mid-winter 1980/81 for two of the Arctic stations are compared with a station in southern Norway (Lillestrom) in Table 3. They conclude that organic air pollutants are deposited in the Arctic through wet and dry deposition.

Although extensive information is available on the chemistry of Antarctic and Greenland glaciers the amount of information available for Canadian Arctic glaciers relevant to the question of transport and deposition of atmospheric contamination, is proportionately small. A complete literature review has not been completed at this time; but, most of the relevant work appears to have been conducted by glaciologists formerly with the Polar Continental Shelf Project (PCSP) and now with the Energy, Mines and Resources, Canada. Much of the glacio-chemistry, as in the Antarctic, has been directed at dating the glaciers themselves and developing further

Table 1. Annual arithmetic mean concentrations in aerosol constituents (a year includes July-June) (from Barrie and Hoff, 1985)

Substance	Akron		Igloolik		Mould Bay	
	80/81	81/82	80/81	81/82	80/81	81/82
Anthropogenic						
*Cr	0.16	0.30	0.062	0.15	0.31	0.32
*Cu	0.78	1.33	0.69	1.13	1.61	1.02
Mn	1.80	1.49	0.45	0.71	0.79	0.87
Ni	0.32	0.38	0.14	0.27	0.48	0.45
*Pb	1.72	1.70	3.61	3.84	2.89	3.22
*Zn	0.30	0.57	0.35	0.67	0.35	0.41
V	0.36	0.62	0.21	0.47	0.28	0.56
*Zn	2.80	3.48	3.80	3.45	2.82	3.79
H ⁺	6.3	7.4	4.0	5.9	6.5	9.2
NH ₄ ⁺	82	102	77	95	72	125
SO ₄ ²⁻	890	1052	667	966	738	1036
NO ₃ ⁻	55	74	62	71	59	67
Halogens						
Br	3.8	8.9	5.7	14	7.0	16
I	0.43	0.49	0.96	1.83	0.45	0.46
F	2.0	7.8	7.2	5.8	5.4	6.7
Sulfur						
Na	121	158	229	313	179	243
Cl	114	182	368	585	251	354
K	11	16	17	31	15	11
*Mg	92	94	99	129	69	63
Soil						
Al	—	146	13	—	45	—
*Ba	0.50	0.37	0.16	0.21	0.42	0.47
*Ca	201	139	83	94	35	29
*Fe	86	86	16	21	36	29
*Ti	0.49	1.31	0.68	—	0.35	0.34
*P	2.79	1.67	1.37	0.93	3.11	1.12

*The fraction soluble in concentrated nitric acid.

Table 2: Gas concentration (pg/m³) of Chlordane isomers at Mould Bay, N. W.T. (from Hoff and Barrie, 1985)

Date 1984	Chlordane		Nonachlor	
	Trans	Cis	Trans	Cis
June 19-20	1.7	1.3	1.2	0.2
June 21-23	0.61	1.1	1.0	nd
June 29	0.45	1.5	1.2	Tr
June 30-July 1	0.80	1.6	1.4	0.30
July 2-4	1.1	1.7	1.4	0.27
July 5-9	1.1	1.8	1.5	0.40

Table 3: Comparison of measured concentrations of chlorinated hydrocarbons in the Arctic₃ and at Lillestrom, southern Norway. Range and mean value in pg/m³, number of samples in parenthesis (Oehme and Ottar, 1984)

Location	Time	Pentachloro- benzene	Hexachloro- benzene	o-Hexachloro- cyclohexane	γ-Hexachloro- cyclohexane	Σ:α Σ:γ
Lillestrøm		30-78 43 (5)	55-234 162 (7)	347-1230 875 (5)	154-410 318 (5)	1.3
Bjørnøya	Sep-Oct 1980	3.3-6.2 4.5 (5)	29-45 40 (5)	217- 516 367 (5)	15- 42 27 (5)	
My Alenland	Sep-Oct 1980	5.1-23 11 (4)	50-85 71 (4)	708-1290 912 (4)	25- 50 43 (4)	
Mean		8	56	645	35	1.18
Bjørnøya	Feb-Mar 1981	7.0-31 18 (5)	59-188 111 (5)	185-270 273 (5)	12- 16 14 (4)	
My Alenland	Feb-Mar 1981	6-37 22 (5)	71- 95 86 (5)	161-274 223 (5)	13- 17 14 (5)	
Mean		20	99	223	14	1.18

understanding of glacial processes. Only recently has attention been directed to the use of the glacial record to identify environmental trends in the Arctic.

Koerner and Fisher (1982) report on the chemistry of an ice core taken on the Agassiz Ice Cap on northern Ellesmere Island, NWT in 1977. Acid and/or conductive peaks are at the snow surface in May and although this seasonal trend is irregular, the increase is gradual over the winter. Concentrations of Ca, Na, K, and Mg as well as insoluble particulates are also at a maximum in the spring. These authors conclude that the annual trend in acidity and increased conductivity are compatible, and that the increased conductivity is due almost entirely to increasing levels of acid in the snow. As well, they observe that the acid trend began to increase from general Holocene levels sometime in the early 1930's. A similar study of snow from a pit on Devon Island Ice Cap, covering the period 1942 to 1972, showed no conductivity trend over this period (Koerner and Fisher, 1982). This discussion was taken up by Barrie et al (1985) who reported on the recent glacial chemistry of several ice cores in the Canadian high Arctic and compared these results with available air chemistry information. These authors observed that ice melt water acidity and conductivity are well correlated. The long term conductivity record for Agassiz Ice Cap (1912 - 1981) shows that there is strong seasonal fluctuation in ice conductivity and hence acidity. This fluctuation parallels that observed in Arctic air chemistry which peaks between December and April. Further, the glacial chemistry record indicated little variation in the magnitude of Arctic air pollution in the first half of this

century but a marked increase by about 75% between 1936 and 1977 as European SO₂ and NO_x emissions increased. The associated increase in winter-time snowpack acidity was inferred to be from 8 µequ/L in the first half of the century to 14 µequ/L in the late 1970's.

Previous studies of the environmental chemistry of the Arctic snow pack are limited. There may have been numerous studies, such as hydrological studies, which have included chemical measurements of the snow but these have not been directly relevant to the question of environmental contamination and therefore are not included here. McNeely and Gummer (1984) undertook a study of the snowpack chemistry in east-central Ellesmere Island, NWT, between 1979 and 1981. This is the only known comprehensive study of snowpack chemistry in the high Arctic. Analyses included physical parameters, major ions, nutrients, metals and synthetic organic compounds. Forty percent of the measurements of laboratory pH of the melted snow pack samples were below the atmospheric equilibrium pH of 5.6. The sites varied with respect to major ion chemistry dependent upon the proximity to the ocean and the geochemistry of the local bedrock and surficial materials. As for metals, only Cu, Al and Fe were consistently detected in the snow pack. Measurable concentrations of polynuclear aromatic hydrocarbons (PAHs), Lindane (γ-BHC) and its isomer α-BHC, dieldrin (HEOD), and DDT were detected at a number of sites. Polychlorinated biphenyls (PCBs) were detected in some samples, but contamination was suspected and the results were not reported. These data will be discussed below, in the context of the 1986 results.

Shewchuk (1984) sampled the water and snow pack of six lakes in the southeastern portion of the NWT in March, 1984. The results of this study, unfortunately, are not available at this time.

PURPOSE OF THIS STUDY

The rather lengthy introduction above is intended to provide the background for the study of the snow chemistry of the Arctic initiated in 1986. There is irrefutable evidence of the presence of anthropogenic contaminants within the biological system of the Arctic and work has been initiated to assess the potential effect of these contaminants upon natives dependent upon these biota as a major component of their diet. The pathway or pathways of these contaminants; however, in the Arctic ecosystem remains in question. Background contamination of the oceans has been suggested as one possible source. The deposition of contaminants to the Arctic snow pack from the atmosphere has been substantiated; however, the magnitude of this pathway is unknown.

Snow is the dominant form of precipitation in the districts of Keewatin and High Arctic averaging around 60% at Baker Lake to as much as 90 to 100% in the High Arctic. In contrast, the Western Arctic, although it receives a lot more precipitation in total, receives proportionately less precipitation as snow, as little as 30%. In addition, the High Arctic and Keewatin

tend to be dominated by the Arctic gyre more so than the Western Arctic which is heavily influenced by intrusions of moist Pacific air masses. Consequently, it is appropriate to study the snow in the Keewatin and High Arctic whereas a study of atmospheric deposition in the Western Arctic would be best achieved through the use of large volume precipitation samplers capable of sampling both snow and rain. Thus, the geographical scope of this study has been limited in this way.

Sampling of the annual snowpack provides an integrated sample for the critical period of transport and deposition of contaminants in the Arctic. As well, the glaciers of the high Arctic provide the opportunity of an historical record for deposition of contaminants. Consequently, this study of snow chemistry has been undertaken for the purpose of:

- i. determining the presence of a spatial pattern in the deposition of anthropogenic contaminants to the Arctic snowpack;
- ii. investigating the presence of a temporal trend of anthropogenic contaminants within the record provided by the snow accumulated in glaciers;
- iii. assessing the significance of atmospheric deposition of contaminants to the Arctic snowpack and speculate on the potential significance of this source to the aquatic environment; and,
- iv. identifying, as feasible, from consideration of the presence of trace compounds and elements within the snowpack, the potential sources for the contaminants.

The snow sampling program is intended to sample as many widely distributed sites within the districts of Keewatin and Franklin, N.W.T., as is logistically feasible, over a two or three year period. Every effort will be made to ensure spatial continuity between years but the cooperative efforts under which the logistics of this study are organized will limit this aspect. In addition, one or two glacial snow pits will be excavated to a depth of approximately 40 years before present (B.P.).

The methods to be used throughout this study were established and tested within the initial year of this study, 1986. The remainder of this report is directed to a brief description of these methods and the presentation and discussion of preliminary results.

METHODS

1) Field Methods

The in-field liquid phase continuous flow extraction technique used in this study for the extraction of organic compounds was essential to provide detection of the ultra trace concentrations expected in the snow. Also, this technique was expected to minimize the possibility of sample contamination and most certainly simplified the logistics and expense of shipping samples from the Arctic to the laboratory in southern Ontario. However, a large volume snow sample (approximately 40 L of water equivalent) representative of the annual snow pack

was required for each site. The surface 1 to 3 cm of snow were removed from the area to be sampled prior to the collection of snow in order to minimize the contamination by hydrocarbons from the transportation device (aircraft or snowmobile). The sample was taken upwind of the direction of travel and the parking location of the aircraft or snowmobile at a distance of 200 to 300 m, if time permitted. In several instances, deteriorating weather conditions or other logistical constraints precluded the use of a buffer of this magnitude from the airplane.

At each site a pit was excavated to the full depth of the annual snow pack such that a clean cross-section was available for sampling. The pit was dug using a clean acetone rinsed metallic shovel which was further cleaned in nearby snow. Originally, a teflon coated aluminum shovel was employed; however this shovel did not withstand the force of shovelling this hard snow and a clean steel shovel was used thereafter. The snow, which was generally quite hard, was placed into 50 L cardboard boxes lined with new teflon bags (2 mil thickness). The bags were either sealed air tight at the pit sight or were folded closed and sealed air tight at the first possible opportunity. Several centimetres of snow were left undisturbed at the bottom of the pit so as to minimize incorporation of terrestrial material other than that which had been incorporated within the profile through wind action. Additional samples were taken in wide mouth 500 ml polyethylene containers for the purpose of determining snow density. These were filled in such a way as to represent the entire section (as density varies with layers) thereby providing a composite

density measurement; and, whenever possible, were replicated.

Snow samples were returned to the base (either Baker Lake or Resolute Bay) and were stored frozen, outside. Melting occurred at room temperature within the original sampling bag. The bags were not opened until immediately before extraction. In most cases, extraction was undertaken while some snow remained in the sample such that the temperature of the sample at the time of extraction was in the 0 to 2°C range. Logistics precluded all samples from being handled in this manner with some samples being extracted at relatively warm temperatures.

ii) Field Laboratory Methods

Once the sample (consisting of from 2 to 10 boxes of snow per site) were melted, the water was extracted. Two versions of a prototype continuous flow liquid/liquid extractor were used. The Baker Lake samples were extracted using an impellor to produce the mixing whereas all samples extracted at Resolute Bay were extracted in a newer version which incorporated a centrifugal pump to provide the mixing. Details of the extractors design and efficiencies are available from Dr. Goulden (P.O. Box 5050, Burlington, Ontario, Canada, L7R 4A6). The change in extractors is not expected to have a noticeable change upon extraction efficiencies as the pumping rate, which is the primary variable, was maintained at 500 mL/minute for all samples.

The extractor is constructed of glass and teflon except for the stainless steel components of the impellor or the centrifugal

pump. These components and all feed lines, which were also of glass or teflon were thoroughly cleaned using pesticide grade acetone and hexane rinses followed by a rinse of either Milli-Q (organic free) water and/or sample water. Milli-Q water plus 150 mL of Dichloromethane (DCM) followed by a rinse of sample water was used for all Baker Lake samples. Inadequate quantities of Milli-Q water at Resolute Bay required the use of sample water plus 150 mL of DCM as a first rinse followed by a rinse of sample water. Dichloromethane was the solvent employed for the extraction. The DCM was kept sealed until used at the site. The particular batch lot of DCM had been pretested for impurities prior to use; however, DCM blanks were submitted to the laboratory with the samples.

Upon completion of the extraction of approximately 40 L of sample water, the extract was removed from the extractor into 0.5 L amber glass bottles with teflon lined caps. The extractor was rinsed with water remaining in the extractor and finally with clean DCM with all of the extract and added DCM and a small quantity of the sample water being collected within the glass sample bottle. These bottles and cap liners had been washed, rinsed with pesticide grade acetone and hexane and baked for eight hours prior to being sealed and shipped from Regina to the two operational centres. The bottles were uncapped immediately prior to filling and were then re-capped, sealed and stored frozen until shipped to the laboratory in Burlington, Ontario.

Simultaneously with the extraction, each sample bag was subsampled for total metals, major ions and trace element

analyses. The samples for metals and trace elements were placed in 250 ml Teflon bottles which had been washed in accordance with routine WQB procedures (Environment Canada, 1984) and double rinsed with sample water. These samples were preserved using 1 ml of 50% HNO_3 and were refrigerated until delivery to the laboratory. The major ion samples were stored in 1 L polyethylene bottles, pre-washed in accordance with routine WQB procedures (Environment Canada, 1984) and subsequently double rinsed with sample water. These samples were refrigerated until delivery to the laboratory. Since aliquots were removed from each sample bag to make up the metals/trace element and major ion samples, they represent a composite sample. The pH of each sample bag and of the bottles collected for determining snow density were also determined at the time of extraction as well as the water temperature of each bag.

The Resolute Bay samples were spiked prior to extraction for the purpose of assessing extraction efficiencies. Spiking procedures were:

(i) DCM Spikes

- (a) d-BHC - 100 μL of 1 ng/ μL solution added to the initial 150 ml DCM;
- (b) Ethylan - 100 μL of 1000 ng/ μL solution added to the initial 150 mL DCM;

(ii) Water Spikes

- (a) B-BHC - 100 μL of 1 ng/ μL solution added to the first sample bag;
- (b) Endrin - 100 μL of 1 ng/ μL solution added in equal amounts to each sample bag.

All samples were analyzed at Water Quality Branch National Laboratory, Environment Canada, Burlington, Ontario. The procedures used in the preparation of the samples and the analytical methods will be documented in a final report.

RESULTS

i) Field Sampling

A total of four sites were sampled out of Baker Lake using aircraft. These sites were Hayes River, Brown River above Brown Lake, Ferguson River below O'Neil Lake and the Lorillard River. All of these sites were co-located with Water Resources Branch hydrometric stations. A fifth sample was collected using a snowmobile to gain access to a site about 3 km northwest of the village of Baker Lake. This site was upwind, with respect to the prevailing winds, of the settlement. All of these sites were sampled between April 29 and May 1, 1986, prior to the onset of any spring melting.

Seven sites were visited in the high Arctic Islands using fixed wing aircraft. These were the Ice Island, Agassiz Ice Cap on northern Ellesmere Island, Alexandra Fiord on Ellesmere Island, Devon well site near Griffin Inlet on Devon Island, Gascoyne well site near Cape Ricketts on Devon Island, Pedder Point on Eglinton Island and Maryatt well site near Drake Point on Melville Island. In addition, a sample was collected in the Resolute Bay area about 2 km north of the airport. These samples were collected between May 7 and May 21, 1986, prior to

any above freezing temperatures at any of the sites.

Two sites require further comment. First, the Ice Island is literally that and has provided a natural floating scientific research station in the Arctic Ocean. Its location at the time of visit was $80^{\circ} 58.8'N$, $97^{\circ} 41.3'W$. Unfortunately, this visit was unanticipated and only a limited sample was collected (2 boxes). Also, due to a very short time on the "ground" made necessary by deteriorating weather conditions, this sample was collected within about 50 m of the runway. Although it was not obviously disturbed, this sample may be considerably influenced by the relatively heavy traffic of motorized vehicles and aircraft.

Second, the Agassiz Ice Cap site was occupied for a period of five days during which a snow pit was excavated about 5.5 km south of the main camp site. This site was selected because of its remoteness to the camp and previous activities on the Ice Cap. From this pit, annual snow pack samples were collected for the 1985/86, 1984/85, 1983/84, 1982/83 and 1981/82 snow seasons. In addition, two replicate samples were collected from the surface (i.e. 1985/86 snow season). Finally, ice core sections were recovered from storage at the site. These cores were collected in 1977 and were from deep in the ice cap representing a period prior to anthropogenic effects.

Preparation of the ice cores upon return to Resolute Bay was somewhat different to the snow samples. The ice cores were collected, as noted above, in 1977 and had been quartered and stored in polyethelene bags in a snow pit on the ice cap since

that date. Therefore the potential for contamination existed from both the coring procedure as well as the storage techniques. In preparation for sampling these cores, they were removed from the polyethelene bags and sealed in acetone/hexane rinsed teflon bags wherein they were allowed to melt at room temperature for 12 hours. Subsequently, the bags were opened and the melt water removed and the remaining ice thoroughly rinsed with acetone and hexane. The solvents and additional melt water were pumped from the bags and the ice was subsequently rinsed again with ultrapure water. This water and any additional melt water was pumped from the bag prior to resealing. The ice was then allowed to melt and was treated in the same manner thereafter as the snow samples.

The sampling sites and other field information are presented in Table 4.

ii) Analytical Results

The analytical chemistry of the snow samples is continuing. Preliminary information is available for major ions, physical parameters, metals and trace elements, Polyaromatic Hydrocarbons (PAHs), Toxaphene, Organochlorine Insecticides (OCs) and Total PCBs. These data are provisional at this time and the final reported values may change.

The major ions and physicals data are presented in Table 5. It should be noted from Table 4 that a large proportion of the sample sites had replicate samples submitted for major ion and physical analyses. As a result of comparison of these replicates from the first run (A), a number of anomalous values

Table 4: Summary of snow chemistry field information, 1986

SITE NAME	WATER L.	BROWN L.	FITCHESON L.	LOBILLARD L.	BAKER LAKE	RESOLUTE BAY	AGASSIZ ICE CAP L-1-1
LATITUDE	67° 32'.0" N	66° 02'.0" N	65° 28'.0" N	64° 15'.0" N	64° 18.0' N		
LONGITUDE	94° 05.0' W	91° 50.0' W	95° 03.0' W	90° 26.0' W	94° 05.0' W		
DATE SAMPLED	April 29, 1986	April 30, 1986	April 30, 1986	April 30, 1986	May 1, 1986	May 7, 1986	May 10, 1986
# OF BOTTLES	3	3	3	3	3	3	3
AV'GE TEMP. (°C)	15.2	14.8	16.5	18.3	18.6	15.0	1.7
AV'GE pH OF BOTTLES	7.4(7)	7.8(7)	7.4(7)	6.4	6.9(7)	7.1	6.3
AV'GE WATER VOL. (ml)	201	180	194	157	187	148	156
AV'GE DENSITY	0.40	0.38	0.39	0.32	0.37	.34	.31
# OF ROCKS	9	5	8	10	7	5	5
AV'GE TEMP	3.5	2.9	1.9	2.5	1.8	12.7	4.3
AV'GE pH	6.2	5.3	5.5	5.2	5.6	7.1	5.5
DATE OF EXTRACTIONS	May 1, 1986	May 3, 1986	May 3, 1986	May 3, 1986	May 3, 1986	May 13, 1986	May 15, 1986
# OF EXTRACTIONS	2	1	2	2	2	2	2
# OF M.I. SAMPLES	3	4	4	4	4	1	1
# OF METAL SAMPLES	3	4	4	4	4	1	1
SPIERS (Y or N)	N	N	N	N	N	Y	Y

Table 4: (continued)

SITE NAME	ACASSIZ ICE CAP 1-1-2	ACASSIZ ICE CAP 1-1-3	ACASSIZ ICE CAP 1-2	ACASSIZ ICE CAP 1-3	ACASSIZ ICE CAP 1-4	ACASSIZ ICE CAP 1-5	ALTEAMONA FLOED 76° 33' W 75° 47' W May 16, 1986
LATITUDE							
LONGITUDE							
DATE SAMPLED	May 10, 1986	May 10, 1986	May 10, 1986	May 10, 1986	May 10, 1986	May 10, 1986	May 16, 1986
# OF BOTTLES	-	-	3	3	2	2	3
AV'GE TEMP. (°C)	-	-	10.3	9.3	9.8	10.0	7.2
AV'GE pH OF BOTTLES	-	-	5.6	6.4	6.0	6.4	6.3
AV'GE WATER VOL. (ml)	-	-	143	176	169	199	150
AV'GE DENSITY	-	-	.33	.36	.34	.40	.30
# OF BOES	5	5	5	5	5	5(-1)	4(-1)
AV'GE TEMP	6.6	5.3	5.6	1.4	0.9	3.9	1.7
AV'GE pH	5.6	5.5	5.5	5.5	5.4	5.6	7.1
DATE OF EXTRACTION	May 16, 1986	May 15, 1986	May 16, 1986	May 20, 1986	May 20, 1986	May 18, 1986	May 19, 1986
# OF EXTRACTIONS	2	1	1	1	2	2	1
# OF S.I. SAMPLES	1	4	1	4	1	4	1
# OF METAL SAMPLES	1	4	1	4	1	4	1
SPIES (Y or N)	Y	Y	Y	Y	Y	Y	Y

Table 4: (continued)

SITE NAME	ICE ISLAND	CASCADES	DEVON	AGASSIZ ICE	AGASSIZ ICE	PEPPER PT.	MARVATT
LATITUDE	00° 58.8' N	DEVON I.	DEVON I.	CAP (CORE 101-104)	CAP (CORE 111-116)	HELIXTON I.	HELIXTON I.
LONGITUDE	91° 41.3' W		75° 04.3' W		75° 38.2' W	75° 38.2' W	76° 20.3' W
DATE SAMPLED	May 14, 1966	May 16, 1966	May 16, 1966	1977	1977	110° 48.3' W	100° 56.4' W
# OF BOTTLES	-	3	3	-	-	May 21, 1966	May 21, 1966
AV'GE TEMP. (°C)	-	18.7	18.3	-	-	3	3
AV'GE pH OF BOTTLES	-	7.0	7.6	-	-	17.3	17.3
AV'GE WATER VOL. (ml)	-	-	170	-	-	5.0	4.7
AV'GE DENSITY	-	-	.34	-	-	101	105
# OF BOXES	2	5	5	-	-	.38	.38
AV'GE TEMP	6.5	6.8	13.0	13.0	11.7	1.1	1.0
AV'GE pH	5.0	7.2	7.7	5.9	5.9	5.7	5.0
DATE OF EXTRACTION	-	May 20, 1966	May 22, 1966	May 22, 1966	May 22, 1966	May 23, 1966	May 23, 1966
# OF EXTRACTIONS	1	1	1	1	1	1	1 (destroyed in shipment)
# OF M.I. SAMPLES	1	1	1	1	1	1	1
# OF METAL SAMPLES	1	1	4	1	1	1	1
SPECIES (Y or N)	Y	Y	Y	Y	Y	Y	Y

Table 5. Major ions and physical data for NMT snow samples*, 1986

Site	Ca	Mg	K	Na	Cl	SO ₄	pH(L)	SC
	(mg/L)							(usie/cm)
Hayes R.	0.23 (6)	0.29 (6)	0.24 (6)	1.68 (6)	3.34 (6)	0.9 (6)	5.41 (6)	15.6 (6)
Brown R.	0.08 (8)	0.07 (8)	0.04 (8)	0.38 (8)	0.93 (8)	0.5 (8)	4.80 (8)	10.2 (8)
Ferguson R.	0.08 (8)	0.07 (8)	0.04 (8)	0.32 (8)	0.76 (8)	0.5 (8)	4.82 (8)	9.7 (8)
Lorillard R.	0.18 (8)	0.06 (8)	0.04 (8)	0.16 (8)	0.40 (8)	0.9 (8)	4.77 (8)	11.1 (8)
Baker Lake	0.06 (10)	0.02 (10)	0.02 (10)	0.10 (10)	0.24 (10)	0.29 (10)	5.13 (10)	4.3 (10)
Resolute Bay	0.82 (2)	0.31 (2)	0.07 (2)	0.87 (2)	2.11 (2)	0.37 (2)	6.42 (2)	13.3 (2)
Agassiz L-1-1	0.08 (2)	0.02 (2)	0.03 (2)	0.04 (2)	0.09 (2)	0.52 (2)	5.09 (2)	4.9 (2)
Agassiz L-1-2	0.02 (8)	0.01 (8)	0.01 (8)	0.03 (8)	0.07 (8)	0.35 (8)	4.99 (8)	4.6 (8)
Agassiz L-1-3	0.02 (2)	0.01 (2)	0.01 (2)	0.02 (2)	0.07 (2)	0.34 (2)	4.98 (2)	4.4 (2)
Agassiz L-2	0.03 (2)	0.01 (2)	0.01 (2)	0.02 (2)	0.07 (2)	0.28 (2)	5.07 (2)	3.8 (2)
Agassiz L-3	0.02 (8)	0.01 (8)	0.02 (8)	0.02 (8)	0.10 (8)	0.22 (8)	5.10 (8)	3.5 (8)
Agassiz L-4	0.02 (2)	0.01 (2)	0.01 (2)	0.02 (2)	0.09 (2)	0.25 (2)	5.10 (2)	3.5 (2)
Agassiz L-5	0.03 (6)	0.01 (8)	0.01 (8)	0.05 (8)	0.24 (8)	0.24 (8)	5.04 (8)	4.0 (8)
Alexandra Fiord	13.2 (2)	37.0 (2)	11.0 (2)	346.0 (2)	540.4 (2)	171.0 (2)	6.60 (2)	2260. (2)
Ice Island	0.14 (2)	0.31 (2)	0.12 (2)	1.54 (2)	3.21 (2)	0.50 (2)	5.46 (2)	15.1 (2)
Gascoyne	1.45 (2)	0.55 (2)	0.58 (2)	3.76 (2)	7.79 (2)	1.10 (2)	6.36 (2)	34.2 (2)
Devon	2.06 (6)	0.14 (6)	0.05 (6)	0.78 (6)	1.61 (6)	0.70 (6)	6.84 (6)	17.8 (6)
Padder	0.17 (2)	0.14 (2)	0.07 (2)	1.08 (2)	2.16 (2)	0.40 (2)	5.33 (2)	11.1 (2)
Maryatt	1.59 (2)	0.12 (2)	0.06 (2)	0.71 (2)	1.48 (2)	4.90 (2)	4.52 (2)	28.1 (2)
Agassiz Core 1	0.10 (1)	0.04 (2)	0.06 (2)	0.09 (2)	0.22 (2)	0.10 (2)	5.86 (2)	2.3 (2)
Agassiz Core 2	0.06 (2)	0.01 (2)	0.09 (2)	0.06 (2)	0.21 (2)	0.07 (2)	5.52 (2)	2.5 (2)

* The number of analytical values included in each reported value is shown in parenthesis (see text).

were observed. Consequently, all of these analyses were repeated (run B). The results presented in Table 5 have been compiled in the following manner. If a value was suspected from run "A", and the results of run "B" confirmed that this value was indeed an outlier, then the outlier was deleted and a mean value for the site was determined based on all remaining data. If a value suspected in run "A" was confirmed in run "B", then no values were deleted and a mean value was determined. In most cases a significant change did not occur between the values in run A and B and thus all replicates and duplicate analyses were included in the determination of the value in Table 5. The variance of these values are not shown as they are not always appropriate due to the small sample size and are small in most cases. The number of analyses, including replicates and duplicate analyses, used in calculating the mean is shown.

The metals and trace element data for the samples are presented in Table 6. As with the major ion samples, a substantial number of these samples were replicated at each site. A small number of inconsistent values were also noted for these data and consequently repeat analyses of all samples was performed. The results of the second run analyses confirmed a number of values as outliers. In the case of certain variables, however, a significant increase occurred in the measured concentrations between run A and B. This increase was observed for Al, Fe and, to a lesser extent, Cr. This increase may be the result of precipitation in the 250 ml teflon sample container from which 70 ml aliquots of sample were withdrawn for each analyses. These data are being investigated further. The

Table 6. Summary of metals and trace elements for NMT snow samples*, 1986

Site	Al	Ba	Cr	Cu	Fe	Mn	Pb	Sr	Zn
	(mg/L)								
Hayes R.	1.650 (6)	0.0163 (4)	0.0040 (6)	0.0026 (6)	1.69 (6)	0.026 (6)	0.0021 (6)	0.0052 (6)	0.0049 (6)
Brown R.	0.027 (8)	0.0011 (8)	0.0011 (8)	0.0011 (8)	0.021 (7)	0.0011 (8)	0.0006 (8)	0.0007 (8)	0.0019 (8)
Ferguson R.	0.020 (8)	0.0017 (8)	0.0014 (8)	0.0011 (8)	0.015 (8)	0.0008 (8)	0.0015 (8)	0.0009 (8)	0.0011 (8)
Lorillard R.	0.062 (8)	0.0028 (6)	0.0014 (8)	0.0015 (8)	0.053 (8)	0.0025 (8)	0.0010 (8)	0.0011 (8)	0.002 (8)
Baker Lake	0.014 (10)	0.0011 (10)	0.0010 (10)	0.0005 (10)	0.012 (10)	0.0008 (10)	0.0006 (10)	0.0004 (10)	0.0008 (10)
Resolute Bay	0.021 (2)	0.0008 (2)	0.0016 (2)	0.0013 (2)	0.022 (2)	0.0014 (2)	0.0002 (2)	0.0027 (2)	0.0012 (2)
Agassiz L-1-1	0.008 (2)	0.0057 (2)	0.0006 (2)	0.0009 (2)	0.0060 (2)	0.0003 (2)	0.0004 (2)	0.0006 (2)	0.0005 (2)
Agassiz L-1-2	0.008 (8)	0.0017 (8)	0.0008 (8)	0.0007 (8)	0.0068 (8)	0.0002 (8)	0.0002 (8)	0.0002 (8)	0.0006 (8)
Agassiz L-1-3	0.009 (2)	0.0032 (2)	0.0013 (2)	0.0013 (2)	0.0075 (2)	0.0003 (2)	0.0002 (1)	0.0003 (2)	0.0009 (2)
Agassiz L-2	0.008 (2)	0.0026 (2)	0.0009 (2)	0.0009 (2)	0.0073 (2)	0.0002 (2)	0.0003 (2)	0.0002 (2)	0.0008 (2)
Agassiz L-3	0.005 (8)	0.0003 (6)	0.0011 (8)	0.0009 (8)	0.0065 (8)	0.0002 (8)	0.0003 (6)	0.0001 (8)	0.0005 (8)
Agassiz L-4	0.016 (2)	0.0004 (2)	0.0034 (2)	0.0007 (2)	0.0014 (2)	0.0003 (2)	0.0004 (2)	0.0001 (2)	0.0005 (2)
Agassiz L-5	0.013 (8)	0.0008 (8)	0.0010 (8)	0.0006 (8)	0.0114 (8)	0.0002 (8)	0.0003 (8)	0.0002 (8)	0.0007 (8)
Alexandra Fiord	0.014 (2)	0.0002 (2)	0.0018 (2)	0.0017 (2)	0.0150 (2)	0.0003 (2)	0.0003 (2)	0.116 (2)	0.0006 (2)
Ice Island	0.011 (2)	0.0002 (2)	0.0011 (2)	0.0014 (2)	0.0113 (2)	0.0003 (2)	0.0007 (2)	0.0034 (2)	0.0011 (2)
Gascoyne	0.023 (2)	0.0008 (2)	0.0012 (2)	0.0016 (2)	0.027 (2)	0.0011 (2)	0.0005 (2)	0.0039 (2)	0.0058 (2)
Devon	0.055 (8)	0.0010 (8)	0.0010 (8)	0.0010 (8)	0.052 (8)	0.0028 (8)	0.0003 (8)	0.0024 (8)	0.0011 (8)
Pedder	0.047 (2)	0.012 (2)	0.0012 (2)	0.0008 (2)	0.065 (2)	0.026 (2)	0.0003 (2)	0.0021 (2)	0.0009 (2)
Maryatt	0.319 (2)	0.065 (2)	0.0016 (2)	0.0020 (2)	2.08 (2)	0.017 (2)	0.0020 (2)	0.0017 (2)	0.015 (2)
Agassiz Core 1	0.011 (2)	0.0031 (2)	0.0012 (2)	0.0028 (2)	0.0084 (2)	0.0004 (2)	0.0013 (2)	0.0004 (2)	0.0040 (2)
Agassiz Core 2	0.010 (2)	0.0060 (2)	0.0017 (2)	0.0037 (2)	0.019 (2)	0.0004 (2)	0.0007 (2)	0.0005 (2)	0.0049 (2)

* The number of analytical values included in each reported value is shown in parenthesis (see text).

interim results reported here are the means of the replicate and duplicate analyses (runs A and B) with confirmed outliers excluded from the calculated value.

Table 7 lists all the PAHs which were frequently detected in the samples. The concentrations are all low, less than 5 ng/L, and to simplify the table only an indication has been made as to whether or not the variable was identified above the analytical detection limit. Samples labelled Agassiz, L-1-1, L-1-2 and L-1-3 are replicate samples of the same layer of snow. The limitation to only three replicate samples was made necessary by the large volumes of snow required to prepare the extracts and the high cost of the analyses. Good consistency is observed between these three samples with the only difference being the detection of Acenaphthalene in Agassiz, L-1-1 at 1.69 ng/L. It should be noted however, that bag blanks and solvent blanks were submitted in triplicate while the water blanks (the "pure water utilized in preparing the bag blanks and rinsing the extraction equipment between runs) were submitted in duplicate.

In addition to the PAHs noted in Table 7, there were a number of infrequent detections. These were:

- i) Quinoline - detected at Resolute Bay (6.89 ng/L) and at Gascoyne (2.20 ng/L). This parameter was not detected in any of the other samples including the blanks.
- ii) Phenanthrene - detected at Hayes R., Lorillard R., and Resolute Bay (4.55, 4.02 and 2.90 ng/L respectively). This compound was also detected in

Table 7. Polyaromatic Hydrocarbons (PAHs) detected in the NWT snow samples, 1986

Site	1	2	3	4	5	6	7	8	9	10
Hayes R.	+	+	+	+				+		+
Brown R.	+	+	+	+						
Ferguson R.	+	+	+	+						
Lorillard R.	+	+	+	+		+		+		
Baker L.	+	+	+	+						
Resolute Bay	+	+	+	+	+		+	+	+	+
Agassiz, L-1-1	+	+	+	+	+					
Agassiz, L-1-2	+	+	+	+						
Agassiz, L-1-3	+	+	+	+						
Agassiz, L-2	+	+	+	+						
Agassiz, L-3	+	+	+	+	+					
Agassiz, L-4	+	+	+	+						
Agassiz, L-5	+	+	+	+						
Alexandra Fiord	+	+	+	+						
Ice Island	+	+	+	+						
Gascoyne	+	+	+	+	+		+			
Devon	+	+	+	+	+					
Pedder Pt.	+	+	+	+		+				
Agassiz, Core 1	+	+	+	+		+				+
Agassiz, Core 2	+	+	+	+		+				
Bag Blank	+	+	+	+	+	+		+		+
Water Blank										
Solvent Blank										

+ = identified above the detection limit

- | | |
|----------------------------------|----------------|
| 1 Indene | 6 Fluorene |
| 2 1,2,3,4, Tetrahydronaphthalene | 7 Quinoline |
| 3 2, Methylnaphthalene | 8 Phenanthrene |
| 4 1, Methylnaphthalene | 9 Fluoranthene |
| 5 Acenaphthalene | 10 Pyrene |

one bag blank at 4.52 ng/L but was not detected in any of the other blanks.

- iii) Fluoranthene - detected only at Resolute Bay at a concentration of 3.22 ng/L.
- iv) Pyrene - detected in Agassiz Core 1, Resolute Bay, and Hayes R. (14.93, 2.55 and 4.15 ng/L respectively). It was also detected in two bag blanks at 3.15 and 6.18 ng/L.

The results of Toxaphene analyses are summarized in Table 8. Determinations were made using ECD detection after capillary GC. The analyses for Toxaphene is based on examining 11 of the many peaks (approximately 200) on the Toxaphene chromatogram. The method is described in detail by Ryan and Scott (1986) as validated by Scott and Ryan (1986). If at least 5 peaks were hit in the sample, it was considered sufficient to conclude that the sample contained Toxaphene and the concentration was determined. Hits on only 4 peaks have been noted but this was not considered sufficient to warrant quantification. Similarly, if 5 peaks were matched but the retention times were not shifted consistent with the standards, the sample was not quantified. Samples not included in these groups were considered not to include Toxaphene. Replicated analyses followed the same pattern as outlined above for PAHs.

Total PCBs and Organochlorine pesticide detections are summarized in Table 9. In this case, measured concentrations have been shown as the values are wide ranging and warrant discussion. Again, the pattern of replication is the same as that used for PAHs.

Table 8. Summary of Toxaphene detections in the NWT snow samples, 1986

Site	A	B	C
	(ng/L)		
Hayes R.			X
Brown R.	0.265		
Ferguson R.			X
Lorillard R.			X
Baker Lake			X
Resolute Bay			X
Agassiz, L-1-1	0.429		
Agassiz, L-1-2	0.376		
Agassiz, L-1-3	0.111		
Agassiz, L-2	0.075		
Agassiz, L-3		X	
Agassiz, L-4	0.171		
Agassiz, L-5	0.200		
Alexandra Fiord	0.240		
Ice Island			
Gascoyne			
Devon	0.294		
Pedder			
Agassiz, Core 1		X	
Agassiz, Core 2		X	
Bag Blanks			X
Water Blanks			
Solvent Blanks			

- Notes:
- If no indication is shown for the site, then Toxaphene was not detected.
 - A - At least 5 peaks matched and thus concentration quantified
 - B - Only 4 peaks matched, not quantified
 - C - Less than 5 peaks but with shifts in retention times relative to standards

Table 9. Organochlorine Pesticides and Total PCBs detected in the NMT snow samples, 1986

Site	HCB	BHD	LIN	HEX	CHC	CHA	EMX	DDE	HEO	PCB
	(ng/L)									
Hayes R.	0.04	5.56	2.00	0.18	0.16	0.16	0.50	0.02	0.54	0.76
Brown R.	0.04	8.12	3.05	0.23	0.22	0.23	0.75	0.05	0.90	1.57
Ferguson R.	0.03	1.4	0.76	0.06	0.07	0.06	0.23	0.01	0.17	0.54
Lorillard R.	0.05	6.46*	1.77	0.10	0.09	0.09	0.32	0.07	0.30	0.89
Baker Lake	0.01	0.70	0.31	0.03	LDL	0.02	0.10	0.007	0.15	0.28
Resolute Bay	0.05	7.42	2.42	0.30	0.34	0.39	0.77	0.05	1.25	1.76
Agassiz, L-1-1	0.008	0.75	0.23	0.41	0.37	0.40	LDL	0.015	LDL	1.00
Agassiz, L-1-2	0.009	1.5	0.20	0.40	0.35	0.35	LDL	0.01	0.05	1.50
Agassiz, L-1-3	0.01	4.89	3.48	0.35	0.40	0.40	1.05	0.01	1.35	0.74
Agassiz, L-2	0.01	0.75	NNS	0.25	0.23	0.23	0.73	0.006	0.94	0.34
Agassiz, L-3	0.04	0.48	NNS	0.28	0.25	0.25	0.75	0.01	0.93*	0.38
Agassiz, L-4	0.03	1.08	0.79	0.07	0.03	0.04	LDL	LDL	0.30	0.41
Agassiz, L-5	0.02	1.15	0.76	0.08	0.03	0.04	LDL	0.007	0.25	0.68
Alexandra Fiord	0.02	0.43	0.22	0.10	0.09	0.08	0.24	0.009	0.83	0.02
Ice Island	0.07	2.83	1.13	0.16	0.05	0.11	0.42	0.05	0.74	1.67
Gascoyne	0.02	1.67	0.85	LDL	0.15	0.15	0.40	0.008	0.45	0.60
Devon	0.10	0.81	0.50	0.07	0.03	0.04	0.10	0.02	0.25	0.67
Pedder	0.05	1.32	1.19	0.14	0.06	0.10	0.27	0.016	0.42	0.71
Agassiz, Core 1	0.03	LDL	LDL	LDL	LDL	LDL	LDL	0.06	LDL	1.49
Agassiz, Core 2	0.01	LDL	LDL	LDL	LDL	LDL	LDL	0.01	LDL	0.68
Bag Blanks	0.006	0.06	0.02	LDL	LDL	LDL	LDL	0.01	LDL	0.59
Water Blanks	LDL	LDL	LDL	LDL	LDL	LDL	LDL	LDL	LDL	0.92
Solvent Blanks	LDL	LDL	LDL	LDL	LDL	LDL	LDL	LDL	LDL	8.8**

LDL = less than detection limit; NNS = not sufficient sample for dilution

* = not sufficient sample for dilution

** = reported as total nanograms of Total PCB in the aliquot of solvent

HCB - Hexachlorobenzene (HCB)

BHD - α -BHC

LIN - γ -BHC (Lindane)

HEX - Heptachlor Epoxide

CHC - γ -Chlordane

CHA - α -Chlordane

EMX - α -Endosulfan

DDE - p,p'-DDE

HEO - Dieldrin

PCB - Total PCB

Organochlorine pesticides other than those listed in Table 9 were detected less frequently. The compounds detected were:

- i) Heptachlor - detected in samples from Agassiz L-4; Agassiz L-5; Alexandra Fiord; Ice Island and Gascoyne (0.01, 0.009, 0.008, 0.015, and 0.006 ng/L respectively). There were no positive detections of this compound in any of the blanks.
- ii) o,p'-DDT - detected at Devon, Agassiz Ice Core 1 and Pedder (0.015, 0.03, and 0.01 ng/L respectively). Positive detections were noted for the Bag Blanks at 0.01 ng/L.
- iii) p,p'-DDT - detected at Brown River, Resolute Bay and Agassiz L-5 (0.08, 0.10 and 0.04 ng/L, respectively). This compound was not detected in any of the blanks.
- iv) B-Endosulfan - detected at Hayes R., Brown R., Lorillard R., Agassiz L-1-1 and Agassiz L-1-2 (0.06, 0.04, 0.04, 0.06 and 0.04 ng/L, respectively). This compound was not detected in any of the blanks.

DISCUSSION

i) Recovery Efficiencies

As noted above, a total of four different compounds were utilized in these samples to assess recovery rates or extraction efficiencies of the method. At this time the results are available for one of these compounds as illustrated in Table 10. Endrin, an old, currently little used organochlorine insecticide, showed efficiencies of greater than 63%, averaging 95%. However, the very high recovery rates well over 100% in a number of samples must be questioned. Excluding all of the samples for which the recovery efficiency exceeded 100% provides a conservative recovery rate of 76%. Further discussion of the efficiencies of the extraction technique will be possible when the analyses are complete for the other spikes.

ii) Ice Core Samples

The two ice cores from the Agassiz Ice Cap were not collected in a manner consistent with the intent of this study. As noted above, these samples were recovered from storage at the Ice Cap. Inspection of the data for these two cores suggests that although the major ion and pH data for these samples may be reasonable, the metals and certainly the positive detections for total PCB and PAHs must be the result of contamination. The core sections were selected from a depth of the glacial ice

Table 10. Extraction efficiencies for high volume snow samples determined by Endrin*

Site	Concentration (ng/L)	Volume (L)	Efficiency (%)
Hayes R.	0.08*	41.5	---
Brown R.	0.13*	41.5	---
Ferguson R.	LDL*	41.5	---
Lorillard R.	0.04*	41.5	---
Baker Lake	LDL*	41.5	---
Resolute Bay	2.18	43.7	95
Agassiz, L-1-1	5.17**	39.65	205 (?)
Agassiz, L-1-2	5.72**	44.65	255 (?)
Agassiz, L-1-3	2.72	39.85	108
Agassiz, L-2	2.80	53.25	149
Agassiz, L-3	2.80	42.3	118
Agassiz, L-4	1.93	40.7	76
Agassiz, L-5	1.51	44.8	68
Alexandra Fiord	1.92	37.4	72
Ice Island	3.03	21.0	64
Gascoyne	2.00	40.45	81
Devon	2.73	40.75	111
Pedder	3.46	39.15	136
Agassiz, Core 1	3.92	16.05	63
Agassiz, Core 2	3.44	25.3	87
Bag Blanks	LDL*	---	---
Water Blanks	LDL*	---	---
Solvent Blanks	LDL*	---	---

= Based on an absolute spike of 100ng of Endrin

* = Sample was not spiked

** = Insufficient sample for dilution

that has been dated well before the time of synthesis of these organic compounds (personal communication with F. Koerner and D. Fisher, Energy, Mines and Resources Canada) therefore precluding the presence of at least the organic compounds other than through contamination.

The possibility of contamination was considered at the time of preparation of these samples and consequently some effort was directed toward the cleaning of these samples as described above. However, as noted by Boutron et al (1985) rinsing of ice cores is ineffective at removing contamination from the coring process and the only effective means seems to be mechanical chisseling and subsampling. Therefore it is concluded that these cores were contaminated during the coring and storage processes and that the analytical results can not be relied upon for metals and trace elements, total PCBs, PAHs and possibly even major ions.

Interestingly, the results for OCs reveal a different picture; that is, a general absence of contamination of these compounds at the ultra trace level in the ice core samples. The measured concentrations for OCs on the ice cores were very low or below the detection limit for all detected compounds except for p,p'-DDE and o,p'-DDT. Thus, it would appear that these samples were also contaminated for these OC compounds but not for the other OC pesticides. The complexity of contamination of these ice core samples is somewhat mystifying at this point. As noted by Boutron et al (1985) contamination of deep glacial ice cores for metals, for example, is difficult to avoid when using a coring process as employed in the collection of these

cores. The pattern of apparent contamination by synthetic organic compounds is more difficult to explain although the feasibility of contamination by PCBs and PAHs under the conditions present during collection, storage and subsequent transportation is highly likely. The potential of contamination of these samples or their ability to be used as an indication of an absence of in-field contamination will be considered further in subsequent discussions regarding Toxaphene and the OC pesticide group.

iii) Major Ions and Physicals

The analytical results for this group of analyses generally showed little problem with respect to outliers among the replicates and the values reported here reflect in almost every case, the results of duplicate analyses. Therefore, the results are presumed to be reliable. Most of the concentrations of the ions are low although some pattern can be noted related to marine influence. The inland sites with lower concentrations include Brown R., Ferguson R., Lorillard R., Baker Lake and the Agassiz Ice Cap. All of the other sites are affected by marine influences with the most noticeable being the Alexandra Fiord site. This sample was collected from the ice of the fiord. These values have not at this time been corrected for the influence of sea salt. The same pattern is indicated by specific conductance (SC) with the high conductance of the Alexandra Fiord site probably due to the incorporation of marine aerosols within the snow sample.

The pH of the snow samples as measured in the laboratory are consistently lower than the field measurements. It is noted

that the field measurements were made at relatively low sample temperatures and were determined for each sample bag and as such the field measurement of Table 4 are means of replicates. This difference between field and laboratory pH is the reverse of that expected since it is conceivable that the field measurements were made on samples that were not fully equilibrated with air and at the low temperatures could contain considerably more CO_2 than the same sample at room temperature, as is the case with the laboratory pH measurements. The increased CO_2 would be present as H_2CO_3 , thereby increasing the acidity of the sample (Koerner and Fisher, 1982).

Considering the laboratory pH measurements, these samples would appear to represent the lowest pH measurements of snow reported for the Canadian Arctic. McNeely and Gummer (1984) reported snow pack pH for east central Ellesmere Island between 5.2 and 7.1 with about 40% of the values less than the theoretical equilibrium pH in the atmosphere of 5.6. The pattern of pH is generally comparable to that noted for major ions with the lowest concentrations occurring inland. Nevertheless, there would appear to be a tendency toward lower pH in the Keewatin, as evidenced by the results for the Brown, Ferguson and Lorillard Rivers, compared with the Agassiz Ice Cap samples. This pattern will require further investigation because large areas of the Keewatin District, including the areas from which these samples were taken, have very low buffering capacity and as such are highly sensitive to acidification of the surface waters (Tebbatts and Gregor, 1986; Lucas, 1986).

iv) Metals and Trace Elements

As noted above, these results are being investigated further in an effort to confirm the reason for the increase in concentration noted for Al, Fe and to some extent, Cr. Therefore discussion will be limited with respect to the data presented in Table 6. There was generally good consistency between the replicate samples submitted for metals and trace element analyses. In the limited number of cases where one of the replicates varied from the others, bottle contamination is suspected but can not be confirmed. This is a reasonable conclusion as each replicate was a composite of aliquots of each sample bag for the site, thereby minimizing the influence of sample contamination.

All of the metals and trace element concentrations are low. As yet the results have not been considered with respect to identifying any spatial pattern; and, although differences do occur between years for the five years sampled from the Agassiz Ice Cap, these are minor. There are no reasons to anticipate large differences in annual metal and trace element concentrations over the last five years of snow pack accumulation in the Canadian Arctic.

The only data for which comparisons are relevant at this time are those of McNeely and Gummer (1984). However, as noted by these authors, the only metals observed in the snow pack samples present in measurable concentrations were Al, Fe and Cu at approximately 40, 80 and 2 µg/L respectively. Occassional detections of B and Zn were noted as was a single detection of

Cd at its detection limit. All other metals including As, Pb, Hg, Se and V were not detected at the detection limit of the methods used. The 1986 survey used analytical methods with lower detection limits for the variables considered; and consequently, the detection of numerous metals and trace elements in these samples which had not been previously quantified.

In most snow pack samples there is the possibility of incorporation of wind blown terrestrial material which could affect the metal and trace element concentrations. The exceptions to this are the samples from the Agassiz Ice Cap. The surface area of the ice cap is such that wind blown terrestrial particles are likely to be minimal. Consequently, the concentrations observed in the Agassiz Ice Cap samples are believed to be representative of the concentrations being scavenged from the atmosphere through wet and dry fall out.

Parameters which were generally noted to be less than detection were Cd, Co, Mo and Ni. Mercury had not been included in the 1986 survey because the available analytical detection limit mitigated against the probability of detection. The inclusion of mercury is being considered for the 1987 sampling program.

v) Poly Aromatic Hydrocarbons (PAHs)

PAHs are derived from the combustion of coal tars. Their presence in the Arctic can be attributed to long range transport and to localized combustion and deposition. Ample evidence of the contamination of the Arctic atmosphere with organic pollutants is provided by Norwegian researchers. Dehme

and Mano (1984) reported on the detection of Pentachlorobenzene, Hexachlorobenzene, α -HCH, and γ -HCH in the atmosphere at a number of sites sampled during 1980 and 1981. Additional information was reported by Oehme and Ottar (1984) and Pacyna et al (1986) on organic air pollutants in the Norwegian Arctic.

Despite this evidence of transportation of PAHs and other organic pollutants to the Arctic by long range atmospheric transport, the possibility of contamination of these snow samples during collection, storage and extraction must also be considered. Since time has not permitted a full consideration of these factors as yet, Table 7 only provides a listing of the parameters which have been detected and the sites at which the detection was made. Noteworthy to this discussion is the fact that the blanks submitted on the sample bags showed detection of the PAHs observed in the snow samples but at somewhat lower concentrations. The bags used to prepare these blanks were new bags, identical to those which had been used for the snow samples, and which had been transported to the Arctic and returned to Regina for preparation of the blanks. Thus the bags had been subjected to the same types of contamination as the bags used for the samples. The organic free water used in preparing the bag blanks showed no evidence of detectable PAHs. These water blanks were stored in washed and fired glass bottles and extracted in the same laboratory as the bag blanks. Further assessment of the contamination problem will be included in the 1987 survey; however, it is believed that the PAH data are obscured by in-field contamination and original contamination of the sample bags. It is believed also that

the contamination predominantly occurred after sample collection, during transportation in the aircraft, outdoor storage at the two field laboratory sites at Baker Lake and Resolute Bay and during the melting process. Under all of these circumstances the ambient air likely contained considerable concentrations of PAHs from aircraft engines and fuel, internal combustion engines and space heating appliances. Despite the use of two, sealed teflon bags for sample containment, it is conceivable the samples were contaminated by gas migration through the bags and into the sample. Further investigation of this problem is proposed on a limited scale for 1987; however, in the interim, it is believed that analysis of the 1987 snow samples for PAHs is not warranted.

Interestingly, McNeely and Gummer (1984) accepted the PAH measurements from their snow chemistry study although all of their results were below the detection limit available in their study. Despite their conclusion that the PCB results were subject to contamination, they did not reach the same conclusion regarding PAHs.

vi) Toxaphene

Toxaphene, or campheclor, is an insecticidal composition produced by the chlorination of at least one of the following: camphene, camphene hydrochloride, or isocamphene. Toxaphene is a complex mixture of some 177 to 200 compounds of which several main toxic components have been identified (National Health and Welfare, 1977). Toxaphene is a synthetic chlorinated hydrocarbon which does not occur naturally in the environment. It was first used in 1946 and its world wide use to the middle

1970's was reported to be over one billion pounds. Most of the world wide production is used for the control of pesticides in the agricultural industry, with much of the product, at least in the United States, having been applied through aerial application. Toxaphene has never been registered for use in Canada except under extremely limited and controlled applications. U.S. applications have been estimated to include approximately 200 million acres (81 million hectares) annually. Use of Toxaphene has been restricted in the U.S. since the early 1980's. Current application figures have not been located at this time. Information on the production and use of Toxaphene in Eurasia has also not been located by the author as yet. However, since it was the major chlorinated insecticide in use in the U.S. in the late 1970's for the control of pests on cotton, cereal grains, oil seeds, vegetables, fruits and nut crops, it is reasonable to suspect that world-wide use has been extensive, at least in the recent past.

Toxaphene can remain airborne as an aerosol when it contaminates aerosol particulates in the atmosphere during aerial application. Toxaphene may also be volatilized from plant and soil surfaces under warm temperatures. It can be environmentally persistent and appears to be strongly bioconcentrated (NH&W, 1977). It is relatively insoluble in water and since both warm temperatures and alkaline conditions enhance dechlorination, it is reasonable to assume that the compound is very stable in the cold, slightly acidic conditions of Arctic snow.

A total of nine snow samples have been judged to contain

confidently quantifiable concentrations of Toxaphene (personal communication with B. Scott, National Water Research Institute, Environment Canada). Other samples, as noted in Table 8, may contain Toxaphene but have not been quantified. It is noteworthy that six of the nine samples containing Toxaphene are from the Agassiz Ice Cap including the three replicate samples from the 1985/86 annual snow pack. The only sample from Agassiz which did not contain quantifiable concentrations of Toxaphene was Agassiz L-3 which represents snow accumulated during the winter of 1983/84. This sample did match on 4 peaks in the chromatogram, whereas it was considered necessary to have a match of 5 peaks from a possible 11 that were being considered prior to quantification (personal communication with B. Scott). In addition to the Agassiz Ice Cap sites, quantifiable concentrations were detected at Alexandra Fiord, Devon Well on Devon Island and the Brown River site. The latter, was the only site within the Keewatin District for which a concentration could be determined.

The presence of Toxaphene in the Arctic snow at the sites noted can be taken to be clear evidence of long range transport and deposition onto the snowpack of anthropogenic toxicants. There is no conceivable application for Toxaphene in the Arctic and further, there is practically no opportunity for contamination of these samples. The bag blanks did show some evidence of Toxaphene, but not sufficient to be quantified, while the solvent and water blanks showed essentially no similarity with the Toxaphene reference chromatograms.

To date, supportive information on the presence of Toxaphene in

the Arctic atmosphere has not been located. Rice et al (1986) reported on atmospheric concentrations of Toxaphene at a number of stations in a south to north corridor of the United States. Concentrations generally decreased toward the northern sampling sites conforming with the general trend of decreasing concentrations with increasing distance from the zones of greatest utilization. This study included a single rain sample collected at Beaver Island in Lake Michigan between September 28 and October 2, 1981. This sample contained 31.6 ng/L of Toxaphene, approximately 100 times greater than the concentrations observed in the Arctic snows. Highest air concentrations in the U.S. study were noted during August and September with concentrations decreasing in the fall.

vii) Organochlorines and PCB

The investigation of organochlorines (OCs) and PCB is continuing using replicate samples; however, the analyses to date for selected routine compounds is interesting indeed. The first point worthy of note is the apparent lack of sample contamination either from the sampling bags or the collection, storage and melting techniques. This is evidenced by the frequent occurrence of "less than detection" (LDL) observations for many of the OCs in the Agassiz Ice Core samples and the Bag Blanks. The exceptions, that is the compounds listed in Table 8 which seem to indicate some contamination from one source or another, are HCB, α -BHC (BHD), γ -BHC (LIN), p,p'-DDE (DDE), and PCB. The indications are not always consistent. Measurable concentrations are noted in the Ice Cores (which are representative of a time well before the synthesis of any of these organic compounds) for HCB, DDE and PCB; whereas,

measurable concentrations were noted in the Bag Blanks for HCB, BHD, LIN, DDE, and PCB. Further, it is noted that both the Water Blanks and the Solvent Blanks showed measurable levels of PCB. Based upon this information it is concluded that:

- i) The HCB and DDE measurements are at least in part due to contamination from some source and therefore can not be considered contaminants of the Arctic snow at this time;
- ii) The PCB measurements are, to some undetermined degree, the result of background levels of PCB within the solvent. The sample bags do not appear to be contributing to the PCB concentrations as evidenced by the fact that the measurements detected in the bags are less than those detected in the so-called pure water (Water Blanks) used to prepare the Bag Blanks. Until this factor is investigated further it is not possible to indicate the level of PCB in Arctic snow; and,
- iii) Both BHD and LIN show minor contamination levels in the Bag Blanks. Since the concentrations of these two compounds are less than detection in the two Agassiz Ice Core samples, it is reasonable to assume that the measured concentrations in the other snow samples are real and are not significantly affected by contamination.

Thus, from Table B it can be concluded that the Arctic snows sampled in 1986 contain detectable concentrations of α -BHC (BHD), γ -BHC (LIN), Heptachlor Epoxide (HEX), γ -Chlordane

(CHC), α -Chlordane (CHA), α -Endosulfan (EMX), and Dieldrin (HED). Most of these compounds were consistently detected in the Agassiz Ice Cap snows for the four preceding years. The only logical source of these compounds is through long range atmospheric transport and wet and dry deposition onto the snow pack of the Canadian Arctic. The data are insufficient at this time to indicate any spatial or temporal pattern; however this should become evident with follow-up sampling.

As noted above, a number of other organochlorine compounds were detected on an infrequent basis. These were Heptachlor, o,p'-DDT, p,p'-DDT and B-Endosulfan. Contamination is believed to be a factor in o,p'-DDT and possibly B-Endosulfan, while the other values appear to be real detections.

The only known published data of the concentration of synthetic organic compounds in Arctic snow for comparison purposes is that of McNeely and Gummer (1984) for organochlorines in the snowpack collected from east-central Ellesmere Island. Positive detections included α -BHC (BHD), Lindane (LIN), α -Chlordane (CHA), γ -Chlordane (CHC), α -Endosulfan (EMX), Dieldrin (HED), p,p'-DDT and o,p'-DDT. These authors note that Heptachlor Epoxide (HEX) and B-Endosulfan were identified at trace levels, below the detection limit. Thus the detected compounds from this study concur with those of McNeely and Gummer (see Table 1); however, the improved detection limits of this large volume technique have permitted the quantification of the compounds where in many cases it was only possible for McNeely and Gummer to report unconfirmed instrument responses. Furthermore, these authors indicated that although PCBs were

Table 11. Summary statistics of pesticide residues detected in snow pack and rime frost samples from east-central Ellesmere Island, NWT (after McNeely and Gummer, 1984)

Pesticide Residue	No. of Analyses	Concentration Range (ug/L)		No. of	
		Minimum	Maximum	Confirmed* Detections	Unconfirmed** Detections
a-BHC	28	<0.001	0.018	21	5
g-BHC(Lindane)	28	<0.001	0.008	10	5
a-Chlordane	28	<0.001	0.002	1	2
g-Chlordane	28	<0.002	0.002	2	5
op'-DDT	28	<0.001	0.004	2	5
pp'-DDT	28	<0.001	0.002	2	5
a-Endosulfan	28	<0.001	0.002	1	2
HEOD(Dieldrin)	28	<0.002	0.004	5	12

- * Confirmed detections include both (i) concentrations above the detection limit, and (ii) concentrations below the detection limit confirmed by GC-MS.
- ** Unconfirmed detections are instrument responses below the detection limit but of insufficient concentration to permit sample "clean-up" and confirmation by GC-MS.

detected they were not reported due to the belief that these samples had been contaminated. PCB concentrations in the snow obviously warrants further investigation in an effort to isolate and/or eliminate the contamination factor in its measurement.

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